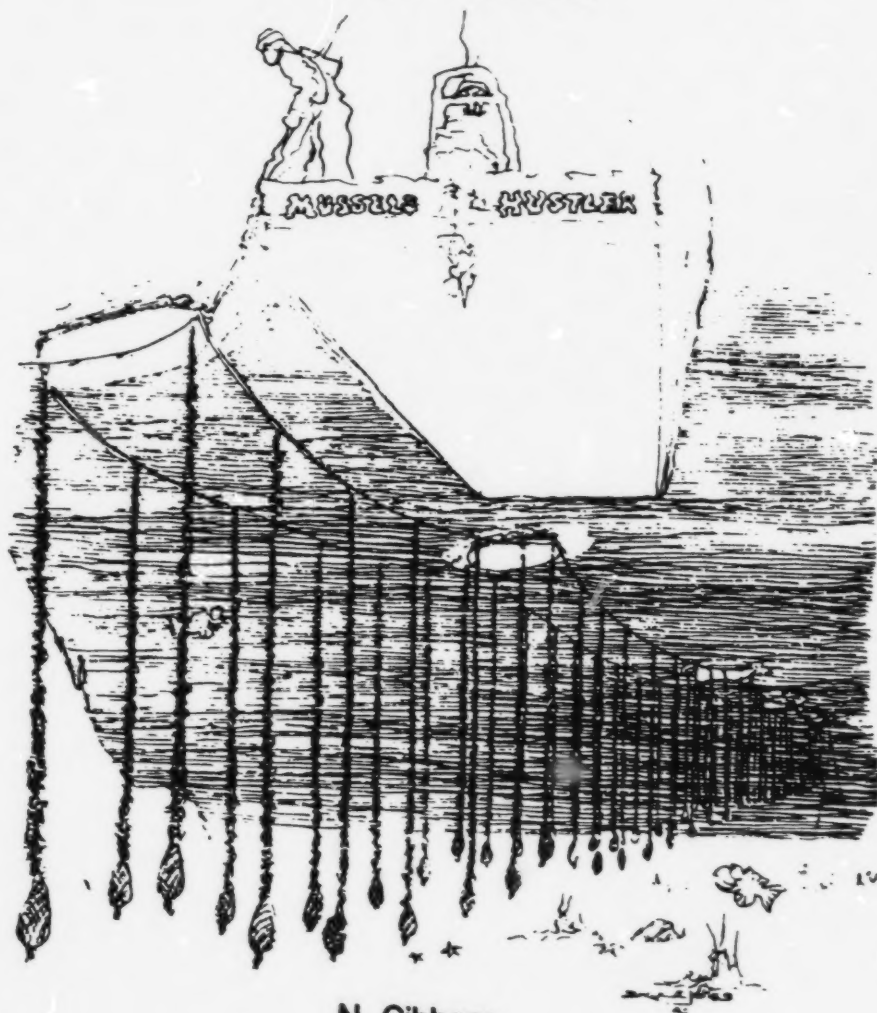


CULTURE OF THE BLUE MUSSEL (*mytilus edulis*) AT REFUGE COVE, BRITISH COLUMBIA

- A PILOT PROJECT -



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Redonda Sea Farms Ltd.

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Province of British Columbia
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by

Norm Gibbons, Redonda Sea Farms Ltd.,
Refuge Cove, British Columbia

Information Report #5

Report on a Provincial-Federal Shared Cost Project

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TABLE OF CONTENTS

	<u>Page</u>
Table of Contents	i
List of Figures	ii
List of Tables	iii
Chronology of Operations	iv
Acknowledgements	v
Introduction	1
Biological Constraints	3
1. Fouling	3
2. Predation	7
3. Weak Byssal Attachment and Summer Mortality	13
Operations	20
1. Seed Collection	20
Grow Out	35
1. Socking	35
Processing and Marketing	44
Summary and Recommended Strategies	49
1. Seed Collection	49
2. Grow Out Strategy	53
3. Formulation of a Grow Out Strategy for the Future	62
4. Recommended System	63
References	65

LIST OF FIGURES

	<u>Page</u>
Figure 1. The location of Refuge Cove, British Columbia. . . .	2
Figure 2. Summer mortality, Refuge Cove, British Columbia. . .	17
Figure 3. Horizontal and vertical collector systems.	22
Figure 4. Workboat utilized for mussel work.	24
Figure 5. Thinning mussel seed by brushing the rope with gloved hand	26
Figure 6. Coiled rope collector with mussel spat	26
Figure 7. A mussel loading device constructed to facilitate socking operation	37
Figure 8. A 6 m mussel "sock" of mussel seed ready for grow out	37
Figure 9. A "harvesting basket" designed by Redonda Sea Farms.	39
Figure 10. Water temperature profile, Refuge Cove, B.C., 1981-82.	55
Figure 11. Water salinity profile, Refuge Cove, B.C., 1981-82.	56
Figure 12. Secchi disc profile, Refuge Cove, B.C., 1981-82 . .	57
Figure 13. Mortality of mussels at Nanaimo, B.C.	59
Figure 14. Mortality of mussels at Bamfield, B.C.	59
Figure 15. Growth rates of mussels by species at two locations	61

LIST OF TABLES

	<u>Page</u>
Table 1. Reference literature outlining mussel productivity projections	1
Table 2. Size range of cultured mussels from April 3, 1982 to March 1, 1983, Refuge Cove, British Columbia . . .	15
Table 3. Summary of byssal attachment of mussels from April - August, 1982, Refuge Cove, British Columbia	16
Table 4. Summary of seed sources and units planted during course of study	28
Table 5. Reproductive condition of mussels (log entries) . . .	30
Table 6. Volume of plankton in tows in Refuge Cove (log entries)	31
Table 7. Bryozoan settlement (log entries)	32
Table 8. Inventory summary of mussels in stock from July 1, 1980 to March 1, 1982, Refuge Cove, British Columbia	41
Table 9. Numbers of cultured mussels of various shell lengths (per kilo and per bushel, Lutz, 1980)	42
Table 10. Socking cost summary/per unit	43
Table 11. Mortalities between harvesting and marketing	45
Table 12. Comparison of mussel seed costs by source	49
Table 13. Cost of horizontal collector system	52

CHRONOLOGY OF OPERATIONS

April - May 1980	Socking 1979 seed
June 1980	Limited marketing - P.S.P. closure
June - July 1980	Horizontal cultching
Sept. - Oct. Nov. 1980	Socking 1980 seed
Nov. - Dec. 1980	Duck predation control - Crop loss - Depth culture
Jan. - April 1981	Equipment construction and socking
May - Aug. 1981	Resocking - Limited marketing - Depth culture
July 1981	Vertical cultching - P.S.P. closure
Aug. - Oct. 1981	Summer die-off - crop loss
Sept. 1981	Thinning vertical cultch
Nov. 1981	1981 seed - depth rope culture developed
Dec. 1981 - March 1982	Clean up from crop loss
Dec. 1981 - March 1982	Experimentation with new replant strategies and substrate

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INTRODUCTION

A large portion of available reference literature suggests that sizable yields of the blue mussel Mytilus edulis may be produced through the utilization of various culture techniques (Table 1). In particular, results of a study assessing the biological feasibility of culturing M. edulis in British Columbia looked encouraging (Quayle, 1978).

Since prolific sets of blue mussels occurred in the Refuge Cove area on a regular and annual basis and Redonda Sea Farms Ltd. wished to extend its oyster tray and string culture operation to include other species solicitation was made to various agencies for support to enter into a project the objectives of which were: (1) to learn to collect, culture, process and market mussels on a commercial scale; and (2) to assess the economic feasibility of a mussel industry in British Columbia.

This report discusses a pilot commercial operation undertaken by Redonda Sea Farms Ltd., designed to study the feasibility of culturing the blue mussel in Refuge Cove, British Columbia (Figure 1).

The results and conclusions in this report are solely the responsibility of the contractor. Editing and publication services were provided by Marine Resources Branch staff.

Table 1. Reference literature outlining mussel productivity projections.

<u>Basis for Productivity Projections</u>		
<u>Source</u>	<u>Yield</u>	<u>Substrate</u>
Quayle (1978)	2 kg/30 cm	vexar sock
MacLeod (1975)	10 kg/m	Norwegian tubing
Herriot (1981)	10 kg/m	rope
Lutz (1980)	10 kg/m	rope
Korringa (1976)	6 kg/m	netlon
Myers (1980)	6 kg/m	netlon

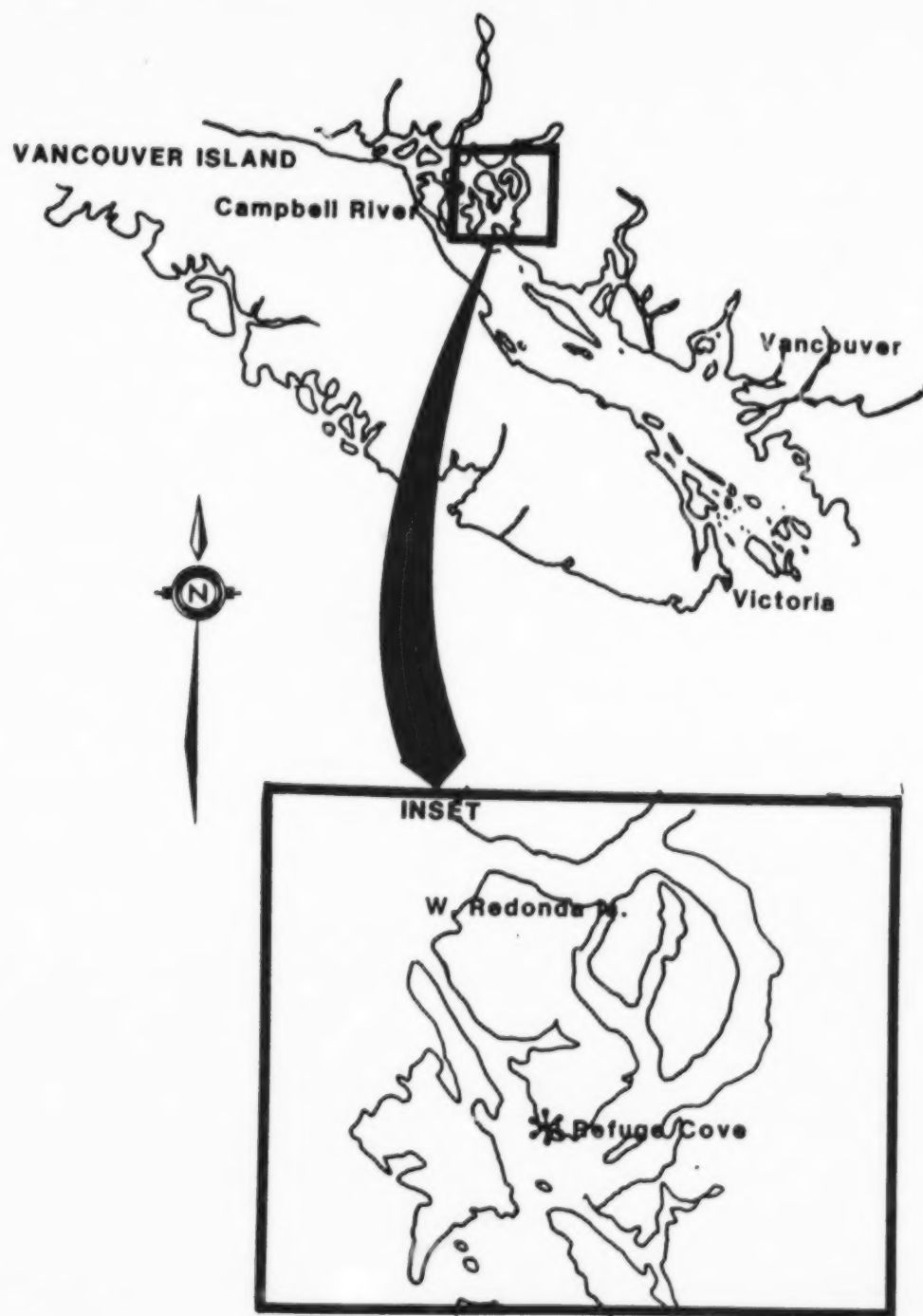


Figure 1. The location of Refuge Cove, British Columbia

BIOLOGICAL CONSTRAINTS

1. Fouling

Fouling is the accumulation of unwanted organisms and associated matter which interfere with growth rates, systems handling, yields and product quality.

Fouling organisms and detritus of little consequence noted during this study included mussel faeces and pseudofaeces, hydrozoans, sponges, various browsers, mud recyclers and detritus eaters, sea squirts, tube worms and algal growth. Most of these occurred infrequently, however, the build up of faecal matter and the presence of the hydrozoans require brief comment.

The decay of faeces and detritus results in the production of hydrogen sulfide gas which is toxic to mussels. This process accelerated during the summer when water temperatures are at their maximum. The distinctive odour of this gas was noticed most often during the resocking operations and it is thought that the presence of this gas may be related to the summer die-off phenomenon.

Hydrozoans bloom prior to the heavy mussel sets in the early summer. Mussels seem to set on the fibrous stalks of the hydrozoans before immigrating to the collector substrate. There was a possibility that the hydrozoans would break loose from the substrate taking the mussel seed with them. This was not a problem at this location, although it has occurred in New Brunswick to the extent that culturists have removed hydrozoan build up immediately prior to mussel recruitment (Bacon, 1981).

In regard to barnacle fouling Quayle (1978) indicated that if the problem

of barnacle fouling could not be solved, then its presence might prove to be the main obstacle to mussel culture in British Columbia. This was not a problem at Refuge Cove. For three years no barnacles set on either oyster or mussel gear even though barnacles do occur on the adjacent intertidal zone. Quayle (1978) describes measures to culture around the barnacle problem.

Fouling organisms of significant consequence were Mytilus edulis and Laminaria.

a. Mytilus edulis

The major fouling organism was the blue mussel itself. In early September 1980, approximately 200 socks containing 1979 stock were completely covered with the summer 1980 mussel set. The mature mussels in these socks were 50 mm+ in size and had not been marketed due to a paralytic shellfish poisoning (P.S.P.) closure in the area. A mussel, 65 mm in length picked from a sock, had over 100 individual young seed attached to it. Densities such as this were typical.

Of the 200 marketable socks of 1979 crop, mortalities reached 80-90%. Initially, it appeared these mortalities were due to the smothering effect of the abundant young seed. But the mortalities appear to be associated more with the summer die-off phenomenon than with the smothering hypothesis.

Nevertheless, a grower must culture around this particular fouling problem. Korringa (1976) describes a heavy mussel set in Spain which is picked off by hand. This can be done where wage rates are low compared with North American standards (\$4.80/day in 1978), however, here such a labour intensive task would be prohibitive. Mussel culturists in Ireland evade the

problem by utilizing different sites: one for seed collection and one for grow out where mussel larvae do not usually occur naturally (Herriot, 1981). Other countries commonly experience sparse mussel recruitments at the best of times and consequently "overlays" do not constitute a problem.

In Refuge Cove, mussel sets are dense especially during June and July when the previous year's crop is close to harvestable size. Catching dense overlays on an entire commercial year's production would be disastrous. Means to avoid the overlay problem might be the utilization of sites on our coast where mussel sets are sparse yet growing conditions are favourable. Such is the case in the oyster industry where seed is collected in one area and grown in another. At Refuge Cove we did not consider this possibility initially. Instead socks on tethers were lowered to a depth where they were free from recruitment. As described elsewhere, mussel setting intensity decreased with increased depth and beyond a depth of 5 m setting was only observed occasionally. The entire 1980 set was socked and tied to 6 m tethers. There was no evidence of overlay on this crop.

b. Laminaria spp.

This species set extensively on our gear each year. Laminaria spp. became noticeable in early March and by mid May had usually achieved a length of at least 1 m. The weight was considerable and added significantly to our farm's floatation costs. The majority of the kelp broke loose from its holdfast by June and fell to the bottom. Laminaria spp. seems to set in the winter months of December and January (personal observation).

Previous to the mussel project we had experienced the effect of this

fouling on our limited mussel culture efforts. We have observed mussels which had set on our gear become covered with Laminaria. In the late spring the weight caused considerable quantities of mussels to become dislodged from their substrates. Many of the socks became fouled with each other due to the tangling effect of the kelp. The problem is described in literature from Maine (Climes and Hamill, 1979) where a sickle on a 5 m shaft is employed to cut loose the kelp.

During the course of the project, we managed to avoid the problems posed by this particular fouling. In the winter of 1980 the crop was lowered on 10 m tethers in early December as a remedial measure to avoid predation by the ducks. When this crop was raised in April 1981, there was little evidence of the presence of Laminaria though it was abundant near the surface. The 1981 crop was similarly lowered on 6 m tethers during the fall and there was no evidence of the kelp on it in the spring of 1982. The tethers, on the other hand, showed a good set which began near the surface and disappeared at the 5 m mark.

During the year, very little fouling was noticed on the crop. However, it became apparent that fouling always managed a foothold on the substrate in places that the mussels did not dominate. An orange sponge, in particular, appeared where the rope was unoccupied by mussel seed. It seemed that fouling was a function of mussel seed density and was partially controlled by even distribution of seed on the substrate. Laminaria occurred on the wooden dowel reinforcers and nowhere else.

2. Predation

Mussels were prey to predators such as perch, crabs, crows, starfish and sea ducks present at the Refuge Cove site. The magnitude of predation varied according to species.

a. Perch

In the summer months, large schools of perch fed from the vertical socks. During the harvesting and resocking operations, they were frequently caught in the wire mesh haul-out basket. Though present in seemingly large numbers, there was no concern about their effect on the crop. Overall, their presence was a benefit since they fed on smaller animals only, thereby thinning out the population. They did not seem to dislodge large clusters as is the case with duck predation. Quayle (1978) mentions that perch feed on mussels less than 25 mm in length.

b. Crabs and crows

Since crabs were rarely present on the verticals it was assumed their pelagic larvae did not settle on the mussel gear. Intertidally, however, crab predation cannot be overstated. On one occasion, difficulty was experienced in shipping mature mussels to market as many gaped and died during shipment. It was thought that intertidal training might extend their shelf life so a tarp was laid out at about an eight foot tide level and spread approximately 125 kg of 50 mm+ size mussels on the tarp. Red rock crab located these

mussels quickly and were quite capable of breaking the mussel shell with their strong pinchers. After one week's duration there were only a few live mussels remaining on the tarp. At a later date, intertidal training in onion sacks was used to effectively stop predation.

On other occasions, following a socking session, considerable quantities of single loose seed remained. This seed was placed in shallow baskets intertidally, with the expectation that it would recluster for future socking. Within a few days, the shore crabs could entirely devastate a basket containing approximately 20 kg of small mussels (less than 25 mm). Myers in Lutz (1980) also gives a graphic example of what crabs can do.

Crows fed on the mussels when they had access to the beach during the daytime low tides.

c. Starfish

Starfish predation is covered extensively in the literature; Myers in Lutz (1980), Quayle (1978), Sutterlin et al (1981), Korringa (1976), Clim and Hamill (1979) and MacLeod (1975).

At the study site the starfish Pisaster ochraceus was of main concern. Their extent varied annually and seasonally. The starfish larvae occur most abundantly following the major mussel set. After three years of observation, it has always been the case that the most dense star set of the year occurred at the time of the most dense mussel set. Quayle (pers. comm.) states that P. ochraceus sets in early fall.

During the fall of 1980, our rope collectors were stripped and the mussels transferred to socks. During this operation and all subsequent

resocking operations, the starfish were removed by hand. The numbers were not great and damage to existing stock was judged minimal.

In the late summer of 1981 (August), the starfish set was intense. A one meter length of 13 mm diameter rope held over 300 individuals (10 mm size) including the new mussel set. This was typical everywhere on the lease. Some oyster tray sets housed thousands of starfish. Initially their presence was beneficial, as they cleaned much of the fouling from the gear. Later, as they grew, they became a threat to the cultured stock.

Fortunately, the one year old crop was below the set zone (5 m) and the new collector gear had been put out during the second week of July following the major mussel set which occurred in early June. The gear was set late in 1981 to collect a light mussel set. Consequently the collectors caught small but sufficient amounts of seed and few stars.

A string culture oyster project illustrates the potential destructiveness of starfish. About 1,500 strings were put out between April and June 1981, and another 700 during the first week of July. The 1,500 strings caught both a heavy sea star and mussel set. The 700 strings caught very little of either. By fall, the 1,500 strings and oysters were completely covered with mussels. In November the mussels averaged about 25 mm in length and the sea stars were slightly bigger. Predation began to be apparent. By the end of January 1982, few living mussels remained on the strings. Many of the sea stars fell from the strings with clumps of dead shell. In two months the starfish had completely destroyed the mussels fouling the oyster strings. A starfish set of this proportion could happen again. Catching a late mussel set seems to be one way to avoid it, however, a thin or sparse set of mussel seed may not always be the goal of the culturist. Removing sea stars by hand

is cost effective only when their number are few and another operation such as resocking is being carried out at the same time. Pulling sea stars from the grow out substrate also tends to dislodge the mussels. In future, studies should be done on dipping sea star infested seed in a saturated saline solution to kill the predator and not harm the mussels. Year old stock should always be safe as it would be harvested before the stars become of size to be a problem.

d. Sea ducks

During the 1980-81 season futile attempts were made to deter predation by sea ducks. During the 1981-82 season their presence was accepted.

Lutz (1980) states: "Loss from predation by sea ducks is perhaps the largest biological problem facing the North American mussel culture industry at the present time." On October 28, 1980, a flock of approximately 300 Barrow's goldeneye sea ducks arrived on the site. One day later, the floatation had risen about 50 mm and two of our longlines measuring 750 m in total length were completely stripped of seed. Over the following weeks, all the remaining seed was stripped from the other longlines, floats and oyster gear. During the last two weeks of November, the ducks concentrated on the vertical socks. By early December all unsocked seed was gone and we estimated at least a 50-75% loss on the socked crop. On December 9, 1980, on the advice of Heritage (Pacific Biological Station, Nanaimo) we lowered our two mussel longlines to a depth of 10 m by attaching 10 m tethers to each float. At that depth, predation was not a problem.

In the following year, on October 15, 1981, a pair of ducks entered the Bay. On the 22nd, there were 250+. By this time, the one year old crop had

been hung on 6 m tethers as was the new seed crop. At, or near, the surface there were approximately 3,300 m of horizontal line, 2,000 floats, 1,500 tray harnesses, 20,000 m of oyster strings and 16,800 m of tether all of which were covered with mussel seed. This was the "sacrifice crop" which the birds ate. The tethered crop of 1981 seed was untouched.

The behaviour of the ducks can be described as follows. The goldeneye arrives in late October. Initially, only a few, but later, one large flock may arrive. Scoters mix with the goldeneye but do not make an appearance until mid November. When the goldeneyes arrive, their feeding can be described as frenzied. Later, as the winter proceeds, they peck away more leisurely and also forage along the shoreline. Periodically, they revert to the frenzied feeding behaviour.

As winter progresses, the large flock breaks up into sub-flocks of 20 or 30 and not all of these remain on the site. When the ducks first arrive, they strip mussels only from horizontal gear. After they have exhausted this supply they feed on vertical gear. It is reported that some sea ducks can dive to depths of 80 m (Heritage, pers. comm.), however, they prefer dives closer to the surface. In the spring, the birds congregate in the outside channel and leave in April. Some flocks are non breeding and stay year-round. P. Jefferds (pers. comm., Penn Cove Mussel Farms, Wash.) reports a resident flock of 300 scoters at his mussel farm. The largest mussel found ingested by a goldeneye was 40 mm. They prefer 20-30 mm seed but dislodge larger seed with their vigorous attacks on the collectors. They do not feed at night.

During the 1980-81 season, the ducks were chased with boats and shot at. The first shot with the shotgun killed three ducks. After that shot, they appeared to know the gun's range and the weapon was never again as lethal.

The .22 rifle scared them off but rarely did it kill a bird. The bird's danger interval was about 30-45 minutes. E. Myers (pers. comm. Abandoned Sea Farms, Maine) reports that the danger interval for the eider duck in Maine waters is about 50 minutes. After being scared away, the flock characteristically appoints a scout to reconnoiter the farm. If the scout thinks all is safe, it stays to feed and then very soon the whole flock lands once again. Hanging out dead carcasses always attracted the scout which landed beside the dead duck apparently not realizing the gravity of the situation. The scout's absence prompted the return of the flock. Chasing the ducks by boat was ineffective.

In March 1981, an AV alarm system was installed. At this point in the study, there were few mussels of value to protect from the ducks; however, it was desirable to test this device. Powered by a 12 volt battery the system is programmed to emit a variety of high frequency signals at various intervals. As a new system it costs \$525. We borrowed one from Specialty Farm Services in Abbotsford. The device was absolutely punishing to the human ear up to a distance of a half mile. All species of birds in the area took no notice of it.

Duck predation is not a concern to the mussel industry in eastern Canada (J. Judson, pers. comm., Prince Edward Island) nor in most European countries. It is a considerable threat on the east coast Atlantic seaboard, U.S.A. and also here in British Columbia and the State of Washington. Blue Gold Sea Farms of Rhode Island feels the only solution is to have a large enough mussel farm to warrant the expenditure of full-time coverage to harass the birds and keep them continually on the move (L. Murray, pers. comm.). Rafts, instead of longlines, could be used on suitable sites and these rafts wrapped in seine

webb to exclude the birds. The use of depth coupled with the provision of a sacrifice crop, was effective in this study. The two longlines lowered to a 10 m depth in December 1980, were subject to very little predation. The extent, however, was difficult to judge as predation was already in the order to 50%+ and the strategy at the time was one of desperation, not empirical design.

During the fall of 1981, 1,000 collector lines were hung on 6 m tethers prior to the arrival of the ducks. At the time of the preparation of this report there was no evidence of duck predation on this seed. It seems duck predation can be thwarted as described above.

Two final comments:

- i) There was little suggestion of duck predation on the vertical oyster strings mentioned earlier. Possibly the sharp flutes of the oyster shell discouraged the ducks.
- ii) Prior to the commencement of the mussel project, there were very few ducks at the farm. During the fall and winter of 1979, the mussels were not stripped from the oyster gear.

3. Weak Byssal Attachment and Summer Mortality

A high incidence of unexplained mortality occurred during the late summer of 1981. The year old crop was affected and mortalities were estimated at 95%+. The phenomenon is often termed "summer die-off" and is frequently reported in the literature. The affected mussels can be characterized as follows:

1. weak and sparse byssal attachments;
2. only year old stock effected;
3. mortalities noticeable in late August but heaviest in September;
4. size 40 mm+;
5. animal gapes and meat decays;
6. shell loses lustre and hardness, crumbles;
7. growth suspended prior to death; and
8. spawned out condition.

Heritage (pers. comm.) reports similar mortalities on nine test sites over a two year period in various British Columbia locations. Jefferds (pers. comm.) reports 40-60% mortalities on an annual basis. Nelson and Arnold (National Shellfish Assoc., 1981 Conference, Portland, Oregon) report mortalities exceeding 81% from South Puget Sound. Incze, Lutz, Watling (1980) report 40-90% mortalities in Maine. Blue Gold Sea Farms, Rhode Island (National Fisherman, March, 1982) report a loss of 75,000 bushels (entire crop). A high incidence of summer mortalities is not reported in Nova Scotia, Prince Edward Island or Newfoundland. Apparently it is not a problem in European countries either (Korringa, 1976).

In April 1982 mussels that ranged in size from 25-35 mm showed strong byssal attachment. By June these animals had increased in size to between 35-40 mm (Table 2) and byssal attachment had begun to erode (Table 3).

It should be noted that in June 1982 these mussels were approximately one year old. Growth after that date is extremely slow. Even ten months later in March 1983, the few remaining live mussels had barely reached a 50 mm market size.

Table 2. Size range of cultured mussels from April 3, 1982 - March 1, 1983, Refuge Cove, British Columbia.

<u>Date - 1982</u>	<u>Size (Range)</u>
April 3	25-35 mm
May 15	30-40 mm
June 21	35-40 mm
July 18	35-40 mm
August 27	40-45 mm
September 19	40-45 mm
November 27	40-45 mm
March 1, 1983	45-50 mm

Table 3. Summary of byssal attachment of mussels from April - August, 1982, Refuge Cove, British Columbia.

<u>Date - 1982</u>	<u>Comments (Surface)</u>	<u>Comments (8 m)</u>
April 3	Numerous, very strong	Numerous, strong
May 7	Numerous, strong	Numerous, strong
June 1	Fewer threads Not as strong	Fewer threads Stronger than surface
June 17	Less than 10/threads mussel-weak-almost fall off when rope breaks surface	Fewer threads Almost as weak as surface
July 1	Some have only 4-5 threads Very weak	Few threads Almost as weak as surface
July 17	Threads elastic Much sloughing evident Completely strip when pulled from water Reinforcers have no effect	Threads elastic Few and weak Sloughing evident Many lost when break the surface
July 30	75% sloughed Half remaining are dead	65% sloughed Half remaining are dead
August 19	Not many left	Not many left



Figure 2. Summer Mortality, Refuge Cove, British Columbia

Summer mortality coupled with weak byssus attachments resulted in a total crop loss once again. On July 20, 1982, the first signs of summer mortality were noticed. A few mussels were gaping and some meats were beginning to decay in the shell. On July 23, a large number of dead mussels were observed (Figure 2). This continued until August 10 when it was concluded that the entire crop had sloughed or died.

On July 17, when it was noticed that byssal attachments were becoming very weak, four ropes with mussel seed were transplanted into lantern net cages. The purpose was to see if the mussels would survive even without their byssal attachments functioning. These mussels, though supported in the mesh cages, died as did the rope suspended crop.

Various hypotheses are put forward to explain the phenomenon:

1. Handling (Heritage, pers. comm.) - transferring mussels from one substrate to another may dislodge byssal attachments and traumatize the animal.
2. Parasite infestation (Olson, Department of Fisheries, Washington, pers. comm.) - a parasite has been found in some mussels in the Southern Puget Sound which induced mortalities, however, the presence of the parasite has not been found elsewhere.
3. Combination of stress and reduced ration (Lutz, 1980) - mortalities follow spawning when glycogen levels are low and spring blooms of plankton have passed.
4. Overcrowding - too many animals compete in the same space for nutrients.
5. Local M. edulis at southern extremity of natural habitat (Barnard, Pacific Biological Station, pers. comm.) - local mussels original habitat is

further north on the west coast and is not able to adapt to great fluctuations in environmental parameters here.

6. Temperature (Incze, 1980) - temperatures above 20°C are common within the Georgia Straits and above the optimum for successful mussel culture.
7. Salinity (Rush and Ayers, 1968) - salinities above 25 ppt are considered optimum. Freshwater influences bring local salinities as low as 15 ppt in many areas.

It may be that the mussels were weak, unhealthy animals from the start. The mussels always exhibited weak byssi and were unable to reclump. Consequently, the excessive handling necessitated replanting into socking material and probably exacerbated the condition. It may be that undisturbed mussels might exhibit a lower incidence of mortality. A lower rate might be tolerated by a mussel business or industry. Therefore, the goal is to design a grow out system which involves less handling. At the same time, the biological and especially physiological explanation for "summer die-off" must be understood. Quayle (pers. comm.) suggests that on the Pacific coast this mussel species is typically an intertidal species and unlike the Pacific oyster may be unable to adapt to a life of complete submergence.

OPERATIONS

1. Seed Collection

Mussel seed was collected from natural beds or by cultching.

a. Wild harvest

Though abundant seed was always available on the artificial collectors, it was necessary to collect and grow out intertidal seed and to compare the economics of using wild seed versus cultched seed. In particular, we were following the recommendation by Quayle (1978). "The technique showing the most promise, particularly from the economic point of view, is the placement of seed collected from wild stocks on rocky beaches in suspended socks after the April barnacle set. This should produce marketable mussels by October or November."

In early April 1981, a local clam digger was contracted to gather 5,000 lb. of beach seed. The price was 25¢ per pound delivered. On April 27, 1982, we received 4,888 lb. of seed. The seed ranged in size from 25-50 mm and was very clean. Optimistically, it was expected the seed would quadruple its weight and market for 80¢ per lb. F.O.B. Vancouver. The initial seed cost was \$1,222.00 with a potential realization at the wholesale level of \$15,640.00 within a six month period. It was socked in netlon (6 m lengths) and hung on 6 m tethers in order to avoid duck predation. One hundred and forty-nine socks were put out weighing approximately 28 lb. each. Six hundred pounds were discarded as single seed as it would not recluster.

b. Cultching

During year one of the project, seed was obtained from oyster gear and 1,400 m of collector rope installed horizontally at depths ranging from 1 to 3 m. During the second year, only vertical 6 m collector ropes were hung.

i) Oyster gear

As the project began in April, 1980, an artificial collectors could not be hung until the summer, the oyster gear was harvested to start the project. Between June and October 1980, seed was harvested from the 1979 set. Six hundred and seventy-four by six meter socks were prepared. The seed ranged from 25-50 mm and each sock weighed approximately 8 kg in air. Much of the seed had sloughed from the oyster gear, however, it was possible to gather 160 kg per 8 m boat length. Also, periodically through the winter, seed was gathered from the gear and another 356 socks were added to the inventory.

ii) Horizontal collectors

In addition to taking advantage of the seed on the oyster gear the need for another 1,400 m of collector rope was calculated. Anticipating a set beginning in mid June the collection system was installed during the first week of June (Figure 3). The collection material was blue polypropylene 13 mm in diameter. Seven 200 m lengths were strung parallel to each other over the water surface.

FIGURE 3a HORIZONTAL COLLECTOR SYSTEM

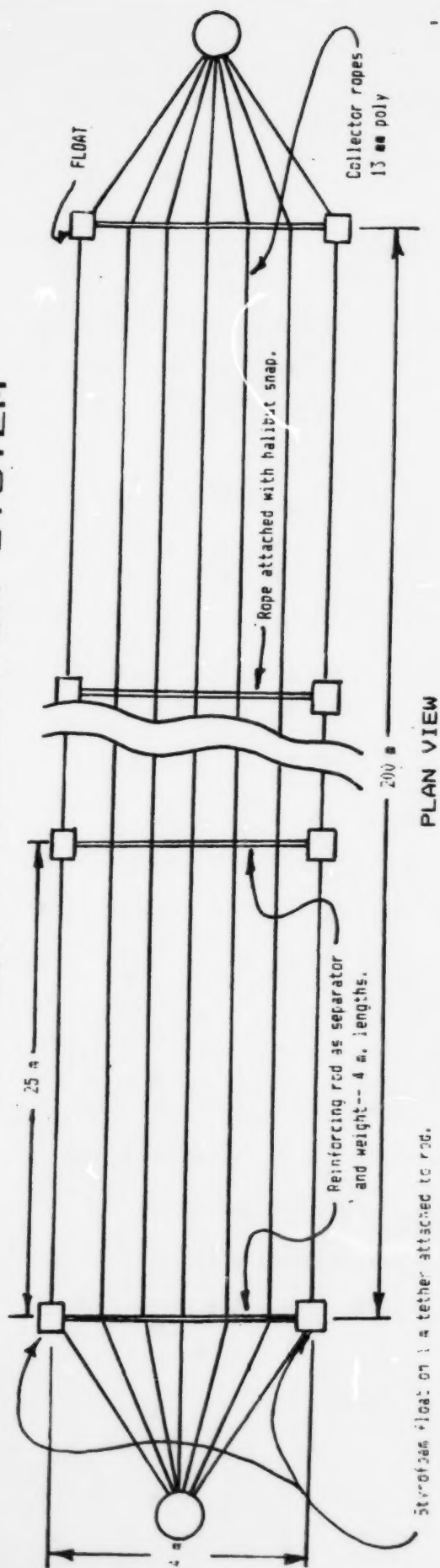


FIGURE 3b VERTICAL COLLECTOR SYSTEM

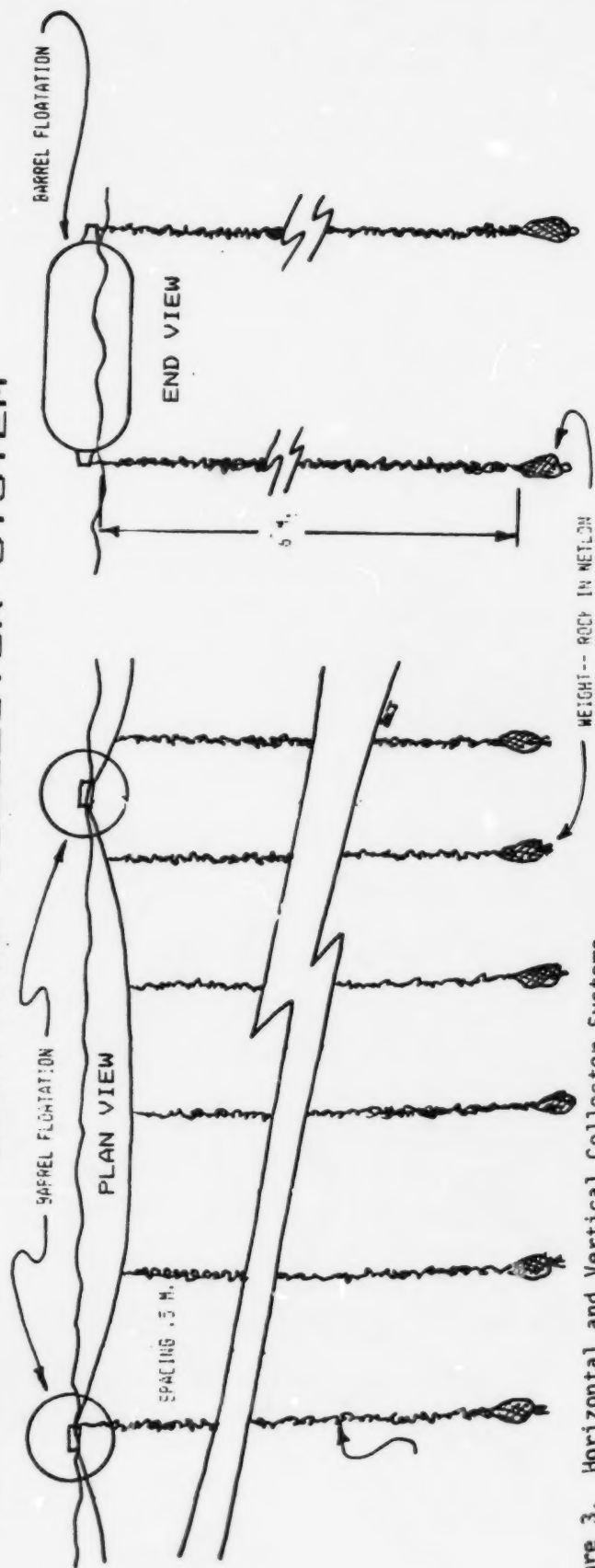


Figure 3. Horizontal and Vertical Collector Systems

Seven 200 m lengths were strung parallel to each other at 0.5 m intervals over the water surface. The ends of the lines were tied to a "scotchman" buoy which in turn was secured by an 18 mm anchor line to 200 kg cement anchors. The material used for spacers was metal reinforcing bar 13 mm in diameter and 4 m in length. The bars were located at 25 m intervals along the length of the lines. Seven halibut snaps were tied to each rebar at 0.5 m intervals attaching them to the collector lines. The bars were located beneath the collector lines so that unfastening would be a simple matter. At each end of the bar was also attached a single float on a 1 m tether. The metal spacers served to sink the collector lines and the floats held them at an approximate 1 m depth. When the whole system was taut it behaved well and there was no tangling of lines. The only problem with the system was that at each low tide the slackness caused the lines to float midway between each metal spacer. In retrospect, however, the sections that floated appeared to collect as well as those that were constantly submerged.

By July 10, 1980, the collector lines show black pepper-like dots in the lay of the rope. On July 31, some of the young seed had attained a length of 3 mm. By August 14, the coverage of the ropes was total. By September 25, some of the seed had attained a length of 20 mm and the mean length was estimated to be 15 mm. On October 3, the first collector line was stripped and transferred to socks. The diameter of the cluster around the rope at this time was 75-100 mm. Harvesting the seed was a simple task. Each collector line was harvested in turn; untied at the "scotchman" and unsnapped from the halibut snaps. By hand, the lines were pulled aboard the boat. The byssal attachments were weak and as the rope came over the side, one person hand stripped the seed into tote boxes. One line could be harvested in this manner

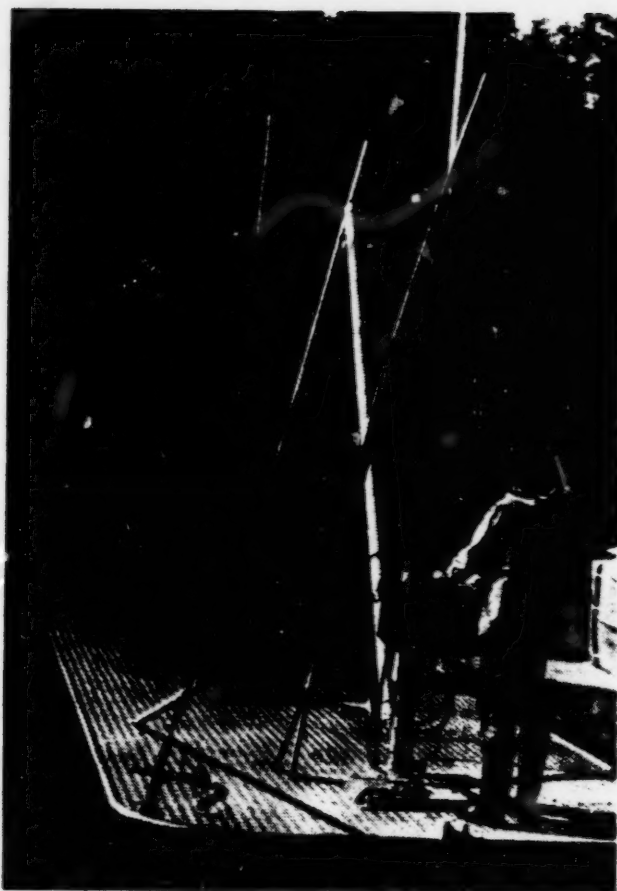


Figure 4. Workboat utilized for mussel work.

by two men in about 40 minutes and 1,600 kg of seed were harvested from the seven lines. There was approximately 1 kg of seed per meter of collector line. It was estimated there were 5,000-7,000 individuals per meter. Very little seed was damaged and the stripping process was carried out over a large tarpaulin so that loose seed could be retrieved.

Between October 3 and November 11, 1980, 774 six meter socks were prepared for the horizontal collectors. Each sock weighed approximately 3 kg.

Our workboat was designed by B. Ketchison of Redonda Sea Farms. The boat is 8 m in length and 2 1/2 m in width. It is all aluminum with a complete skid resistant deck. There is no bilge. The boat is powered by a 20 h.p. outboard and controls and steering are mounted on a stand up helm at the stern of the boat. All corners are rounded and the deck is flush so that tripping or catching up will be avoided. There are two booms and masts, two electric winches and provision for a capstan. The boat is very stable and can carry 4 metric tons easily (Figure 4).

iii) Vertical collectors

During the second summer seed collection methods were changed considerably. Realizing that the oyster gear would catch more seed than required, it was decided to lay out vertical collectors that would serve the double function of acting as grow out substrate as well as collector substrate. If the vertical collectors had not been successful the oyster gear would have supplied enough seed. It was suspected that handling was traumatic to the mussel and that resocking and transplanting was economically



Figure 5. Thinning mussel seed by brushing the rope with a gloved hand.

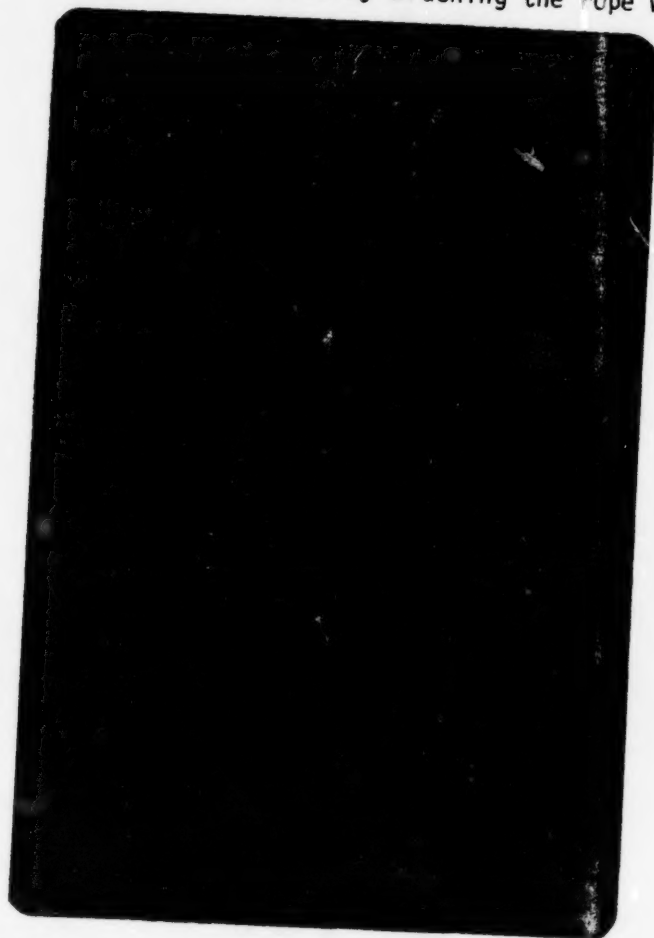


Figure 6. Coiled rope collector with mussel spat.

prohibitive. The goal was to recruit a light but even set over the length of the collector.

A double longline, 200 meters in length was installed. Japanese barrel type 50 gallon floats were used as separators as well as floatation. To the longlines were attached 1,000 6 meter blue polypropylene 13 mm diameter ropes. The ends were weighted with rocks held in used netlon sock bags so that ropes would hang vertically. Ropes were hung during the first week of July, 1981, to miss the major set which usually took place on the site during mid June.

In early August, seed was evident on the ropes. Some were still white and 2-3 mm in length. The 1,000 ropes were thinned at this point so that seed remained only in the lay of the rope. This was done by brushing our hands firmly down the rope and dislodging the small seed on the outer surfaces of the rope (Figure 5 - photo). Later in October the ropes were thinned again as required and wooden dowels were inserted every 0.5 m as reinforcers to prevent sloughage. Six meter tethers were then attached to each rope. The tethers were added to avoid duck predation.

The catch was inconsistent with the heaviest setting near the surface. Below 5 m there was little catch and some ropes did not collect at all. We estimated 375 of the 1,000 ropes caught sufficient quantities to be of commercial value for grow out.

A summary of the quantities of seed collected from various sources during the course of the study is shown in Table 4.

During the third summer (1982) seed collection methods were once again changed considerably.

Mussel seed collection involved experiments with various collector substrates. Also, attempts were made to more accurately predict the mussel spatfall.

Table 4. Summary of seed sources and units planted during course of study.

<u>Source of Seed</u>	<u>Grow Out Substrate</u>	<u>Size At Replant</u>	<u>Units From Source*</u>	<u>Weight/Unit At Replant</u>
Oyster Gear	Netlon	25-50 mm	1,030	8 kg
Wild Harvest	Netlon	25-50 mm	149	13 kg
Cultching Vertical	Rope	No Replant	1,000	No Replant
Cultching Horizontal	Netlon	12-30 mm	774	3 kg

*6 m lengths

c. Spatfall prediction

Dates for setting out collectors were determined by inspecting reproductive tissue of mature mussels (Table 5) by examining water samples from surface plankton tows (Table 6) and by watching the build up of bryozoan on the long lines (Table 7).

The various collectors were put in place on June 10, 1982, when the bryozoan coverage on the longlines was judged about ten days old from first visibility. Experience from the past told us that bryozoan build up always preceded a mussel spatfall by two to three weeks. By July 19, all of the collectors were completely covered with spat and the size was about 1-2 mm.

The plankton tows showed that larvae would be settling from June 28 on and the comments on reproductive condition confirm spawning from June 1 on.

Making observations in these three ways assists the grower in timing the spat collection regime. The easiest key for making these decisions is observation of bryozoan growth. Analysis of water samples and examination of body tissue are aids to confirm what the grower already knows.

i) Coiled rope

Instead of hanging 6 m ropes vertically, some were coiled bringing the entire rope collector within the first 2 m of the surface achieved complete and even coverage of seed (Figure 6). Previously, coverage on vertical ropes was seen especially near the last two meters of the collector.

Table 5. Reproductive condition of mussels (log entries).

<u>Date - 1982</u>	<u>Comments</u>	<u>No. of Samples</u>
May 4	Colour, white-nice condition Thin, watery	7 3
May 24	Full - ripe Thin	6 1
June 1	Thin - spawned out Ripe	6 1
June 17	Spawned out	9
July 3	Spawny Thin - spawned out	4 6
July 20	Spawny Thin	9 1
August 10	Thin	10

Table 6. Volume of plankton in tows* in Refuge Cove (log entries).

<u>Date - 1982</u>	<u>Comments</u>
May 10	Plankton 100 ml
June 1	Plankton 80 ml
June 13	Young larvae - plankton 50 ml
June 18	Young larvae - plankton 40 ml
June 28	Mid-umbone - eyed larvae - plankton 40 ml
July 1	Eyed mussels - some native oysters
July 16	Eyed mussels predominant
August 1	Few eyed larvae - plankton 55 ml
August 10	No larvae - plankton 60 ml

*Volume of plankton settlement in 250 ml jar after 24 hour period.

Table 7. Bryozoan settlement (log entries).

<u>Date - 1982</u>	<u>Comments</u>
June 1	Beginning to show
June 10	Good coverage
June 17	Very matted - no mussels yet
June 24	Some mussels showing on bryozoan
July 2	Bryozoan covered with spat
July 8	Mussels migrating to collectors
July 19	Collectors covered
August 3	Bryozoan disappeared

Once the spat settled then the ropes were uncoiled. The excess seed was brushed off with the hand so that mussels remain only in the lay of the rope. The reinforcers were inserted at this point and the rope hung vertically for grow out.

This method guarantees an even distribution of seed and minimizes handling.

ii) Lantern Pockets and Nets

Five tier lantern nets and pocket nets or pouches made of rigid vexas plastic were employed. These two substrates were used to overcome some of the disadvantages of rope collectors used as grow out substrates. These disadvantages are: (1) the requirement for thinning; and (2) the small amount of substrate available for byssal attachment. On a rope grow out system, mussels eventually hold on to each other rather than the surface of the substrate, consequently reinforcers are required. Spat collectors made of mesh catch fewer spat as mesh size increases; this allows greater attachment opportunity as density decreases.

The mesh size on both substrates was 13 mm. Both types of mesh appeared to collect equally well and coverage was even. Approximately 4-5 mussels settled per 25 mm length of mesh. The seed on the lantern nets settled on the outside and migration to inside areas of the nets was not apparent.

By the time the mussels had achieved an average size of 20-25 mm, byssal attachment was strong and the substrates could be lifted from the water without the mussels sloughing. The pouches weighed about 22 kg and the lantern nets 45 kg out of water. We have little hope that these collectors

will hold mature mussels due to weakened byssal attachment associated with summer die-off.

These substrates do, however, present interesting possibilities and could be used experimentally on sites where summer die-off is not prevalent. They may have advantages over rope or sock methods.

GROW OUT

In approaching the project, we elected to choose one culture methodology rather than experiment with various grow out systems. This decision was rationalized as follows:

1. The goal was to produce tonnage and to evaluate data to measure economic feasibility.
2. Other countries have used netlon successfully, for example Norway, Italy, and Yugoslavia (Korringa, 1976).
3. Quayle (1978), MacLeod (1975) and Clime and Hamill (1979) recommended the sock method.

1. Socking

The material for the grow out phase of mussel culture was a product called "Netlon" produced in Italy. This clear mesh plastic is supplied in 1,000 m rolls. Four mesh sizes and tubular diameters are available. Lengths of netlon are filled with mussels and suspended from long lines. Once suspended the mussels migrate outside of the mesh into more favourable filtering positions. Norwegian and American tubular mesh products are available, but this study tested only "Netlon." Landed cost in British Columbia after all charges is about 6¢ per meter.

Netlon can be ordered in the following sizes: 12E 123; 14E 123; 14E 121; and 25G 123. 12E 123 has a very large mesh size and should only be used for holding mussels that have reached 50 mm market size. 14E 123 and 121 seem

appropriate for 25-40 mm size ranges. 25G and 123 sizes should only be used for very small seed (10-20 mm).

The length of "Netlon" is knotted at one end and the remainder is "socked" over a pipe. The pipe is filled with mussels and the "Netlon" progressively pulled away. Small seed should be socked with a 50 mm pipe diameter and larger seed uses 75 mm pipe. These loading densities were reported by Korringa and Lutz. A mussel loading device was constructed to facilitate this operation (Figure 7).

Two workers prepared a sock of 6 m length in 2.5 minutes (Figure 8). A tether of approximately 30 cm was left at the end of the sock and a double clove hitch was used to tie the sock to the longline. Later, to avoid duck predation, we tied a 6 m tether to each sock and then to the longline. Socks were spaced on the longline every 35 cm. A one cubic foot styrofoam float was attached to the longline after every twelve socks had been attached. As weight increased more floats were attached.

Seed was always harvested and socked on the same day so that the time the mussels were out of water time was minimized. If weather was favourable, this operation was carried out on the work skiff. During inclement weather, socking was done inside.

Often 20-25% of the harvested seed became singles on the floor beneath the mussel loader. Only clumps of mussels stay in the sock as the mesh size must be considerably larger than individual mussels. Various literature sources reported this seed could be suspended in baskets to reclump. The seed produced few and weak byssi and did not prove suitable for resocking. After frequent unsuccessful attempts to recluster the seed, the singles were discarded.

The seed was slow to migrate through the sock. While migration seemed to



Figure 7. A mussel loading device constructed to facilitate socking operation.



Figure 8. A 6 m "sock" of mussel seed ready for grow out.

begin immediately, two to three months was required for the majority of the seed to position themselves outside the sock. Lutz (1980) reports instances of complete migration after only seven days.

Usually, when migration was completed the sock weighed about 30-40 kg out of water. Attachment to the netlon and other mussels was tenuous and a sequence of resocking had to be implemented.

The socks could not be pulled from the water without sloughing en masse. To overcome this problem a harvesting basket made from two five foot diameter crab traps was constructed. The framing was made of 13 mm rebar and the webbing of plastic coated wire. One winch on the skiff raised the longline so that socks could be cut free and at the same time, the basket was positioned under four verticals. The basket was raised with the other winch and the socks coiled into the basket. Mussels were lowered into the loader and resocking began immediately. Resocking four verticals usually produced ten new ones. Later, the basket was re-designed with sloped sides so that the load would center itself in the basket (see Figure 9).

The resocking activity took place between May and August, 1981. Two employees worked steadily at this job three days per week over this period. Approximately 40 socks were lifted on a daily basis and 100 replaced. In early August, the resocked inventory from May appeared to be ready for a second resocking. The cost of labour, boat time, equipment strain and netlon became worrisome because the economics of the operation were unknown. Also, at this time the mussels began to die and the resocking exercise was stopped. From late August to October at least 95% of the crop succumbed to the mortality phenomenon earlier referred to as "summer die-off."

The inventory of mussels in stock from July 1, 1980 - March 1, 1983, and

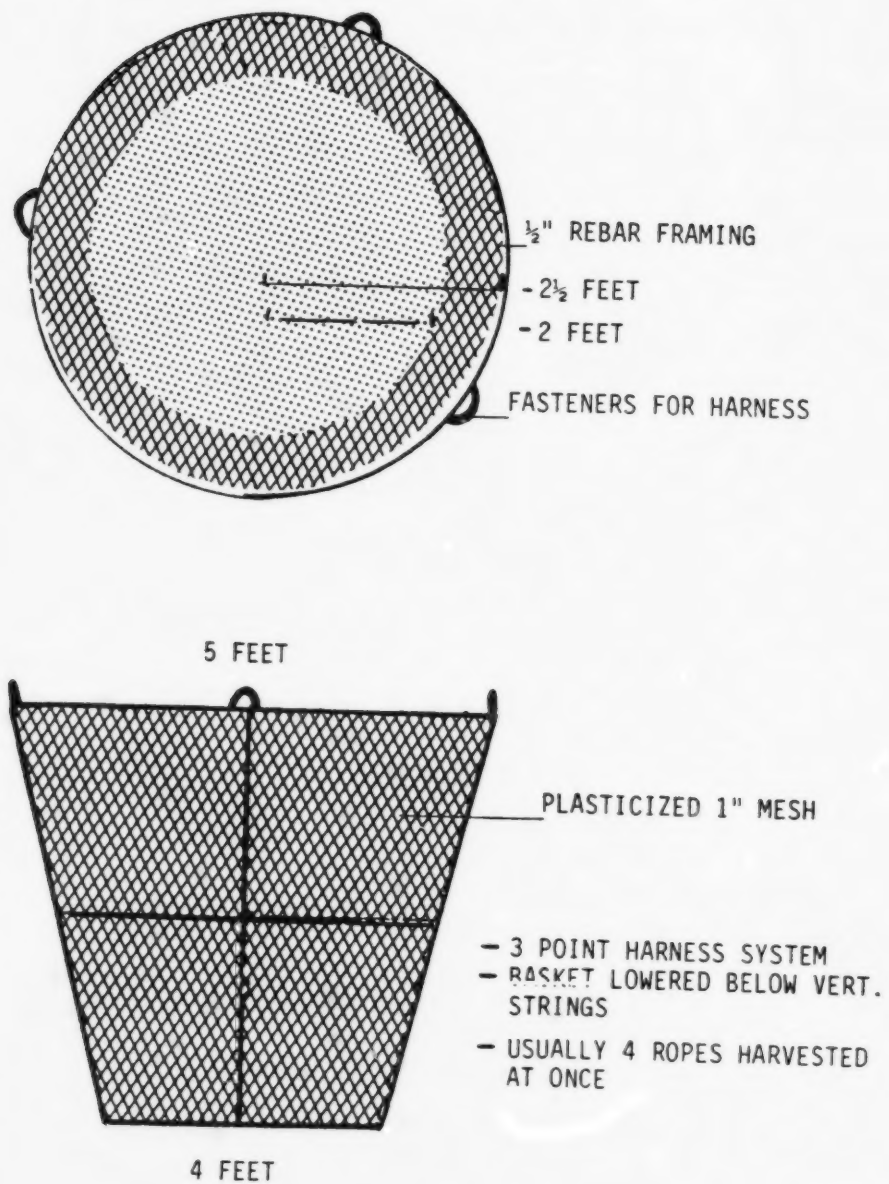


Figure 9. A "harvesting basket" designed by Redonda Sea Farms.

the number of cultured mussels of various shell lengths are shown in Tables 8 and 9 respectively. The number of socks, however, do not represent the number of individuals, weight or condition as resocking increased the number of socks two and one half times and losses as a result of harvesting, duck predation, mortalities and sluffage decrease numbers. The cost breakdown to produce a "sock" is shown in Table 10.

Table 8. Inventory summary of mussels in stock from July 1, 1980 to March 1, 1982, Refuge Cove, British Columbia.

<u>Date</u>	<u>Number of Socks or Ropes</u>
July 1, 1980	128 netlon
November 1, 1980	1,247 netlon
April 1, 1981	2,023 netlon
August 1, 1981	3,240 netlon
March 1, 1982	1,000 (ropes) + 800 netlon

Table 9. Numbers of cultured mussels of various shell lengths
(per kilo and per bushel, Lutz, 1980).

<u>Length in mm</u> <u>+ - 2 mm</u>	<u>Average Individual</u> <u>Live Weight (g)</u>	<u>Count/kg</u>	<u>Count/bu</u>
2-8	0.1	10,000	250,000
25	1.0	1,000	25,000
40	5.9	169	4,000
50	11.3	88	2,000
60	18.4	54	1,200
70	28.1	36	900

Table 10. Socking cost summary/per unit.

<u>First Socking</u>	<u>Cost</u>
Netlon (6 m)	\$ 0.36
Labour (sock & put out) \$6.00/hour	0.60
TOTAL PER UNIT	\$ 0.96
<u>Resocking*</u>	
Netlon	\$ 0.90
Labour	1.50
TOTAL PER UNIT	\$ 2.40

*One sock yields 2 and a half socks

These figures reflect the cost of netlon and labour only. Therefore it is evident that each initial 6 m unit of inventory costs \$3.36 if only one resocking operation is planned. A second resocking would be less expensive because the unit would not expand by two and a half times. Some mussels might be harvested and the density would decrease. The Spanish replant two and three times through a grow out phase.

PROCESSING AND MARKETING

In May, June and early July of 1980 and 1981 harvesting and processing of fresh mussels was carried out in a limited way. During both years there were paralytic shellfishing poisoning (P.S.P.) closures and harvesting was curtailed.

Mussels were either graded out during the resocking operation or entire socks were hand picked. The 50 mm+ mussels were separated and placed in a bucket of saltwater. Those that did not sink were discarded as they were usually dead. The bucket held 12 kg and when it was full the mussels were transferred to onion sacks and suspended in seawater to freshen up. The percentage of marketable mussels by weight per sock never exceeded 30%. Consequently, grading time was very high, and workers were only able to sort 12 kg per hour/each. The other 70% was resocked.

It was realized that grading costs could only be improved significantly if the percentage of mussels per sock were increased dramatically. Unfortunately, this goal was not achieved. Even though the costs were excessive it was necessary to test the product in the marketplace.

On market day the mussels were taken from the onion sacks and washed with a high pressure spray. They were then packaged in wax lined cartons and shipped to Vancouver in a refrigerated truck.

Mortalities were a problem between harvesting and marketing. Individuals died on a daily basis while in the onion sacks. If they were inspected daily, gaping and decaying mussels could always be found. One shipment in 1980 was monitored closely and the following mortalities were noted (Table 11).

Table 11. Mortalities between harvesting and marketing.

July 3 - 150 lbs. prepared and hung in seawater in onion sacks.

July 6 - Dead individuals discarded.

July 8 - Dead individuals discarded and remainder sent to market -
94 lbs.

July 9 - Wholesaler reports that 50% dead on arrival.

During the summer of 1981, grading and washing were combined in one operation. Mussels were sacked and hung over the side overnight, boxed and shipped the next morning. Three ice packs were placed in each box of mussels. Survival was better and shelf life reported by our wholesaler ranged from three to five days.

During the first year of marketing, mortalities and limited shelf life were attributed to our handling procedures. During the second year, following the crop loss due to summer mortality, it was suspected that biological problems prevented successful testing of the various methods used in the study.

Initially the plan was to begin processing limited volumes by hand and then build or purchase processing equipment as volumes warranted. Investigations furnished information from a variety of sources which, in general, agreed that no equipment has been designed yet which declumps, grades and washes cultured mussels without causing excessive shell breakage and trauma to the animal. Franken b.v. (pers. comm.) of Holland and specialists in the design and manufacture of mussel processing equipment were willing to sell their Monobloc KL4 (smallest unit handles 1 m³ of mussels per hour) for \$66,000 U.S. However, they recommended that cultured mussels could only be hand processed if a fresh in-shell product were planned. Myers (pers. comm.) advised that in Maine, the state of the art for washing mussels was to buy the oldest but working Maytag washing machine, put some burlap over the agitator and do a bushel at a time.

During the two year period (1981-82) 3,035 lbs. of fresh mussels in the shell at a wholesale price of 80¢ per pound were sold. Two Vancouver wholesalers were found who would accept weekly 2,000 lb. deliveries at the above price. A request for 2,000 lb. weekly deliveries to Seattle F.O.B. at

80¢ per lb. U.S. was also received. Emmett (1981) independently found a 4,000 lb. per week market in Vancouver. At a retail level, fresh mussels were marketed from \$1.69 per lb. to \$2.19 per lb. in Vancouver. Waterstaat (pers. comm., University of Washington) reports retail prices of \$2.00 per pound U.S. in Seattle. Rumours of \$2.40 U.S. per lb. wholesale prices in Japan and low retail prices of wild mussels in New York and Montreal of 29¢ per lb. were heard. A Boston company lands dredged mussels in Vancouver for 71¢ per lb. The established wholesale price for cultured mussels on the Atlantic seaboard was \$22.50 U.S. per bushel in 1981. At a retail level the price was as high as \$33.00 U.S. per bushel.

The above information leads to the following conclusions:

1. West coast prices are artificially high.
2. The major Vancouver market could have been met by our firm alone if we had reached our projections (4,000 lb./week).
3. Oversupply would mean competition with the cheaper east coast mussel.

Other problems include:

1. The marketplace is interested in a 60+ mm fresh mussel, therefore grow out time optimistically would be 18 months.
2. An entire crop has a tendency to become harvestable at one time, not gradually over a 52 week period.
3. It is costly and difficult to hold a marketable crop for long periods.
4. Condition is best in the late spring when the crop is still undersize (40 mm).

5. Shelf life is limited compared to oysters or clams, therefore distant market potential is also limited.

Based on limited experience in the marketplace and information available, the following scenarios are possible:

1. Cottage operations may evolve similar to oyster tray culture operations. They will compete with each other for a very limited market and produce small amounts.
2. Large commercial operations may evolve but they will go the high mechanization - high processing route, marketing individual quick frozen (I.Q.F.), brined and smoked canned products and others.

SUMMARY AND RECOMMENDED STRATEGIES

1. Seed Collection

In British Columbia the most attractive aspect of mussel culture for a business person is the regular availability of mussel seed at an insignificant cost. Such is not the case with oyster culture, where seed supply is irregular and expensive. The mussel seed cost only becomes significant when one realizes that only a small fraction of the individuals in the inventory will ever come of size and be marketed. Myers in Lutz (1980) feels that five percent of any crop will reach maturity. Here only a fraction of one percent was marketed. Table 12 compares seed costs from various sources during the study period.

Table 12. Comparison of mussel seed costs by source.

<u>Source</u>	<u>Price Per Pound of Seed</u>
Wild Harvest	25¢ lb.
Oyster Gear	12¢ lb.
Cultch	10¢ lb.

a. Wild harvest

The Dutch can drag and harvest 100,000 kg of seed per trip. The Spanish can order a truck load of intertidal seed from the Biscay area as they require it (Korringa, 1976). In British Columbia, we have abundant mussel sets in the intertidal zone; however, it is our impression that very little survives even

its first year. The absence of a wild harvest industry supports this observation. The contractor who provided our wild seed, felt he did better at mussel picking than clam digging and recognized that he had more harvest time per tide. However, he was aware of only a few areas where large (25-50 mm) clean mussels were available in quantity. It quickly became apparent that building a large commercial enterprise based on wild harvest could only be attempted after cataloguing of existing standing crops. This was not done and the exercise should not be completed until it is known how to take large seed and replant it and grow it successfully. Economic feasibility can then be tested against the original seed cost of 25¢ per pound or at whatever price a company is able to acquire this seed.

b. Oyster gear

An existing mariculture operation has both the advantage and disadvantage that its entire underwater gear serves as a collector. For the operator not involved in mussel culture, mussel fouling is a costly nuisance. This fouling agent retards the growth of the cultivated animal as well as adding an additional 50% to the floatation cost. On the other hand, the mussel seed is available for a potential mussel operation. At one point, we estimated that our oyster gear underwater represented a little over five miles of rope. Consequently, each fall, we had vast quantities of seed prior to the annual arrival of ducks.

At a wage of \$6.00/hour, two men harvesting 1,000 lbs./hour result in a seed cost of 12¢/lb.

c. Cultching

The horizontal collector substrate we described earlier is an example of a system useable in the event that wild seed or seed from an adjacent mariculture operation may not be available. The cost of such a system is outlined in Table 13.

The yield of 12-30 mm seed for one year of employment was 3,520 pounds. Therefore, the unit cost was about 10¢ per pound. The collection cost per pound would decrease due to growth and subsequent weight increase if seed were left on the collector substrate. However, the constraints of both sloughing and duck predation, require the harvest at a specific time.

The discussion thus far has not considered the quality of the seed collected. The seed, whether from the intertidal zone or cultch, invariably had weak and sparse byssal attachments.

The literature suggests that high density spatfalls cause weak attachments (Lutz, 1980). Initially, high density spatfalls were thought to be an asset, however, now we realize mussels did not regenerate strong and numerous byssi under the conditions imposed. There may be (i.e., handling trauma and summer mortality) other possible reasons for this phenomenon which have been discussed earlier. Therefore, the extensive recruitment of mussel seed in some areas of B.C. forces re-evaluation of collection strategies.

If various methods of replanting continue to provide costly and/or traumatic to the animal, the goal would be to develop a single substrate culture where the optimum level of seed are distributed evenly and grown out on the collector with minimal handling. In Norway recruitment is light and evenly distributed, therefore little thinning or handling is required. In Ireland, rope collectors are brushed so that seed remains only in the lay of

Table 13. Cost of horizontal collector system.

<u>Equipment (5 year life)</u>	<u>Cost/Year</u>
Rope, anchors, rebar, floats, snaps	\$120
<u>Labour</u>	
Set up and take down/year (4 worker days at \$48/day)	\$192
<u>Harvest</u>	
Stripping (1 workers day at \$48/day)	\$ 48
TOTAL/YEAR COST	\$360

the rope. In Nova Scotia strips of semi-rigid vexar mesh are used and the density of spatfall controlled by varying the mesh size. The larger the mesh size the less the recruitment.

During the second summer and fall of the project 1,000 vertical rope collectors were designed as a single substrate system with the need to concentrate about 1,000 individuals per meter of rope. As reported earlier only 375 of the 1,000 ropes, more or less, fell into this category.

Having observed mussel settlement at this site for three summers, it is concluded:

1. Major recruitment occurred in June.
2. There were low level sets as early as April and as late as October.
3. The set was greatest in the first two meters of the water column.
4. Settlement was always distributed evenly on horizontal collectors near the surface.
5. Settlement on vertical collectors was commercially significant down to a five meter depth but only during the major set.
6. Below a five meter depth settlement was sparse.

These conclusions are based on visual observation and not on careful measurement.

2. Grow Out Strategy

a. Sock vs. rope culture

It took one and a half years into the study to make the decision to abandon the sock method. The method was abandoned because biologically it was

not feasible at this site.

It was assumed that the transplanting and excessive handling required in sock culture exacerbated the phenomenon of summer mortality.

Now that we have witnessed a crop loss on rope cultured stock we are forced to re-evaluate our position. It would seem summer mortality is not solely caused by handling; therefore, biologically, the sock method may be just as viable as the rope method. Economically, however, the material and labour input of sock culture remains significantly higher than rope culture.

b. Depth culture

Depth culture was chosen to avoid duck predation. For three winters, duck predation has been avoided by providing a sacrifice crop of mussel seed near the surface and by hanging the grow out crop at the 6-12 m depth. Depth culture practiced in this way consistently thwarts the duck predation problem whereas no other effective method has been successful to our knowledge.

Depth culture also avoids heavy sets of starfish if mussel seed is lowered before major settlements.

On this site, depth culture has also provided the opportunity to get closer to some optimum environmental parameters for successful culture. As stated elsewhere temperatures of 20°C maximum and salinities of 25 ppt minimum are considered biologically optima for growth, body condition, byssal formation, etc. The environmental data (Figures 10, 11 and 12) illustrate that we were able to locate environmental optima by practicing depth culture. The fact that survival was not increased by these practices suggests that other factors may also contribute to summer mortality.

Therefore, it is apparent that depth culture aids the grower in some

Figure 10. Water temperature profile, Refuge Cove, B.C., 1981-82.

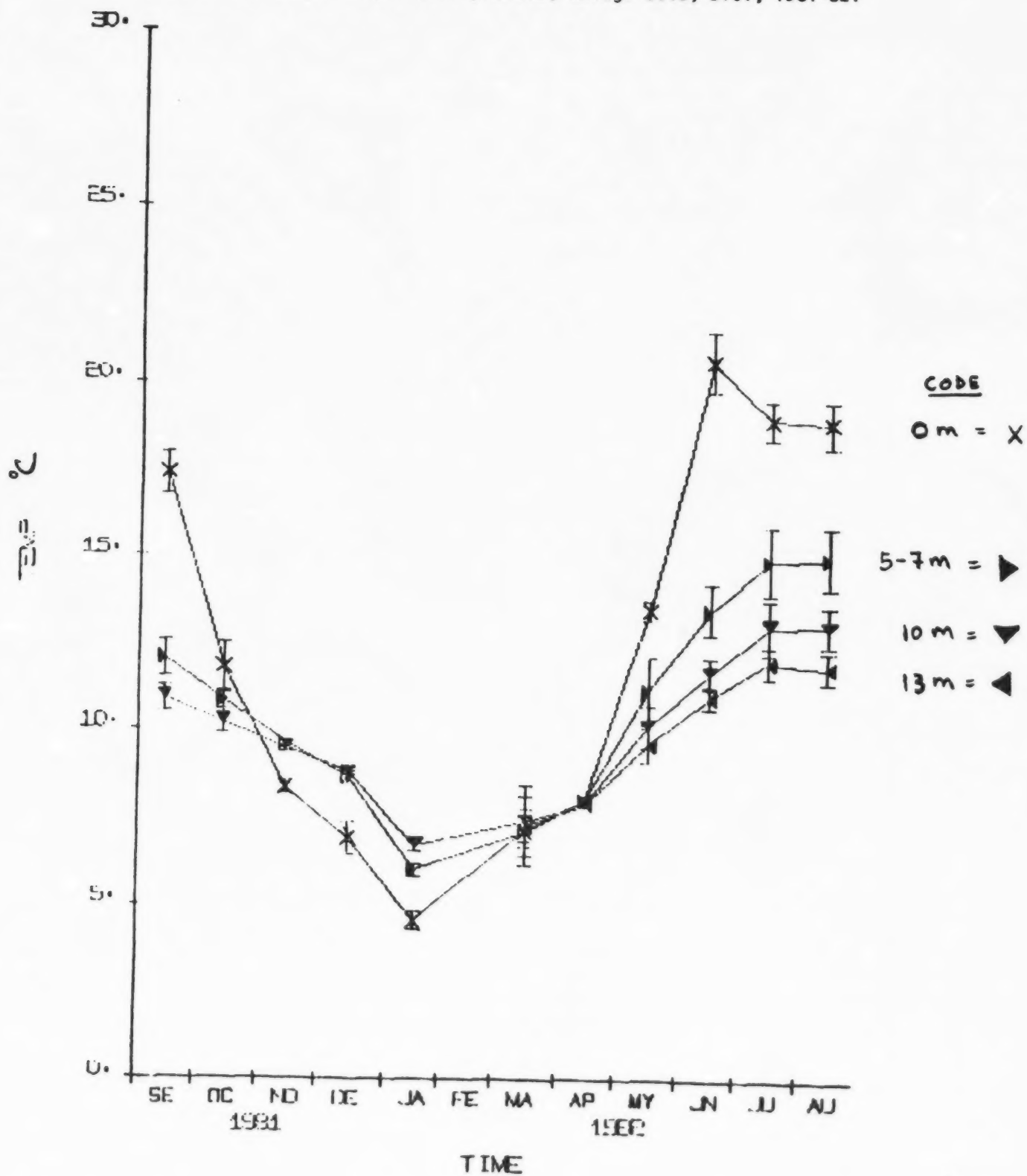


Figure 11. Water salinity profile, Refuge Cove, B.C., 1981-82.

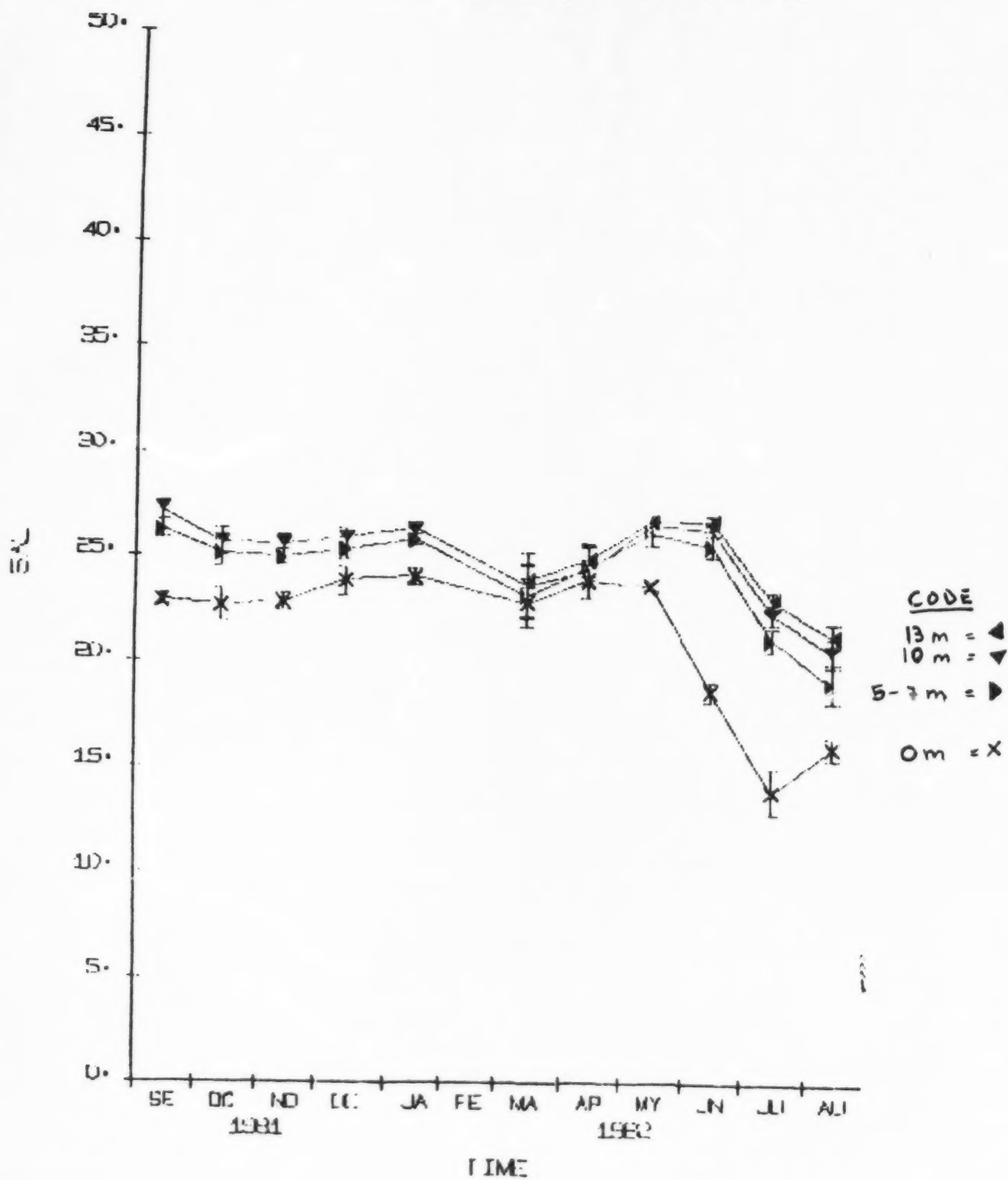
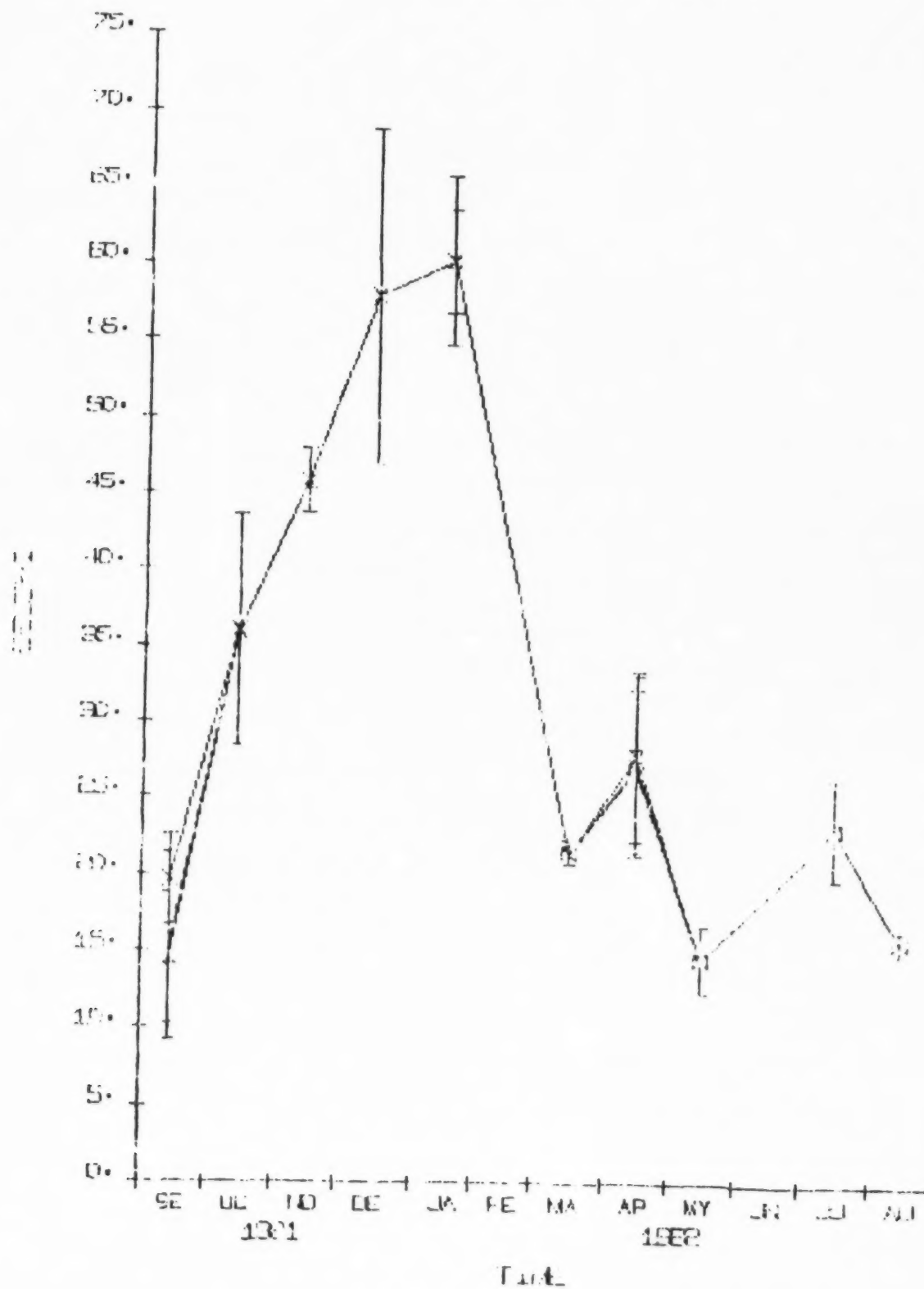


Figure 12. Secchi disc profile, Refuge Cove, B.C., 1981-82.



particular ways; however, it is not the cure-all to the plethora of problems encountered in mussel culture.

c. Site selection

Refuge Cove is a good site for catching reliable and consistent seed supplies. On the other hand, this bay is inappropriate as a grow out site. Ideal grow out sites for mussel culture in British Columbia have not yet been found though they may exist. Heritage (Pacific Biological Station, pers. comm.) has stated that nine test sites in British Columbia all experienced unacceptable losses due to summer mortality and weak byssus attachment. Archipelago Marine Research (Emmett, 1982) recorded mortalities during the summer of 1982 (Figure 13-14) on sites in Bamfield and Nanaimo. By the end of August, cumulative mortalities at the Bamfield site were 35% at the surface and 47% at five meters. Cumulative mortalities by November, 1983 were 75% at the Bamfield site and 90% in Nanaimo. No appreciable weakening of the byssal attachment was noticed on the Bamfield site (Emmett, 1983).

Given these discouraging reports, one is tempted to recommend abandoning all endeavours towards mussel culture in British Columbia or take a more radical turn and support experimentation with other species.

We feel the priority for research is to find sites where the native M. edulis survives until and beyond market maturity. We stress the native mussel for purely economic reasons. Native mussel seed is cheap, as we have demonstrated earlier. This economic advantage may be the key that produces favourable profit-loss statements in the future. The abundance of cheap seed cannot be overstated and is the only reason to pursue mussel culture as a commercial possibility.

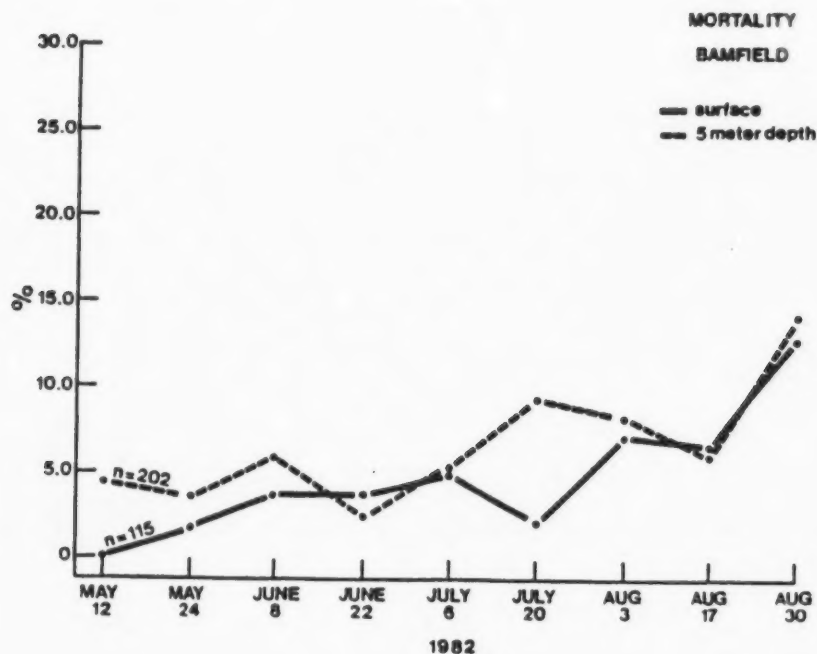


Figure 13. Mortality of mussels at Nanaimo, B.C.

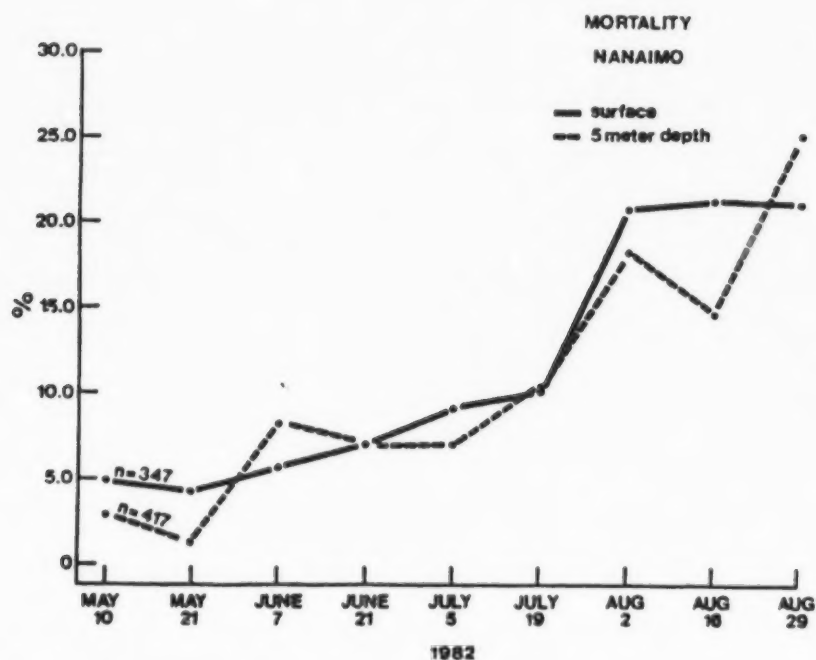


Figure 14. Mortality of mussels at Bamfield, B.C.
(Kindly provided by B. Emmett, Archipelago Marine Research)

In total, 12 sites have been studied in British Columbia which experienced unacceptable summer mortalities. Most of these sites were chosen for convenience and protection from the weather. Possibly sites that are exposed, with considerable wave action and tidal flow and relatively stable hydrographic regimes, should be chosen as test sites. Protected sites in European countries tend to be used for mussel collection whereas grow out invariably occurs in less protected open areas. Emmett (1982) has independently come to this conclusion as well. Other problems are created by culturing in exposed areas; however, if the mussel exhibits strong byssal attachments and immunity to summer mortality then the new problems can be solved.

d. Other Species

If the native mussels continue to prove unsuitable then limited research should be undertaken with other species and/or strains. Mytilus californianus seems to be the likely candidate. It is native to British Columbia and the possibility of collecting seed in the wild exists. Preliminary work has been done with this larger mussel. The mussel is not prone to summer mortality (Figure 15). Heritage (pers. comm.) has also grown limited numbers of M. californianus and observed very few mortalities. The mussel starts slower than Mytilus edulis but catches up and eventually passes M. edulis in size

Byssal attachment is very strong. If wild recruitment proves unfeasible, then the possibility of setting eyed larvae in a hatchery situation exists. This has been done with limited success in Washington (Dr. K. Chew, pers. comm.). The question of market acceptance needs to be explored as the meat colour tends to be orange to red and may not be preferred by North American consumers.

GROWTH COMPARISON

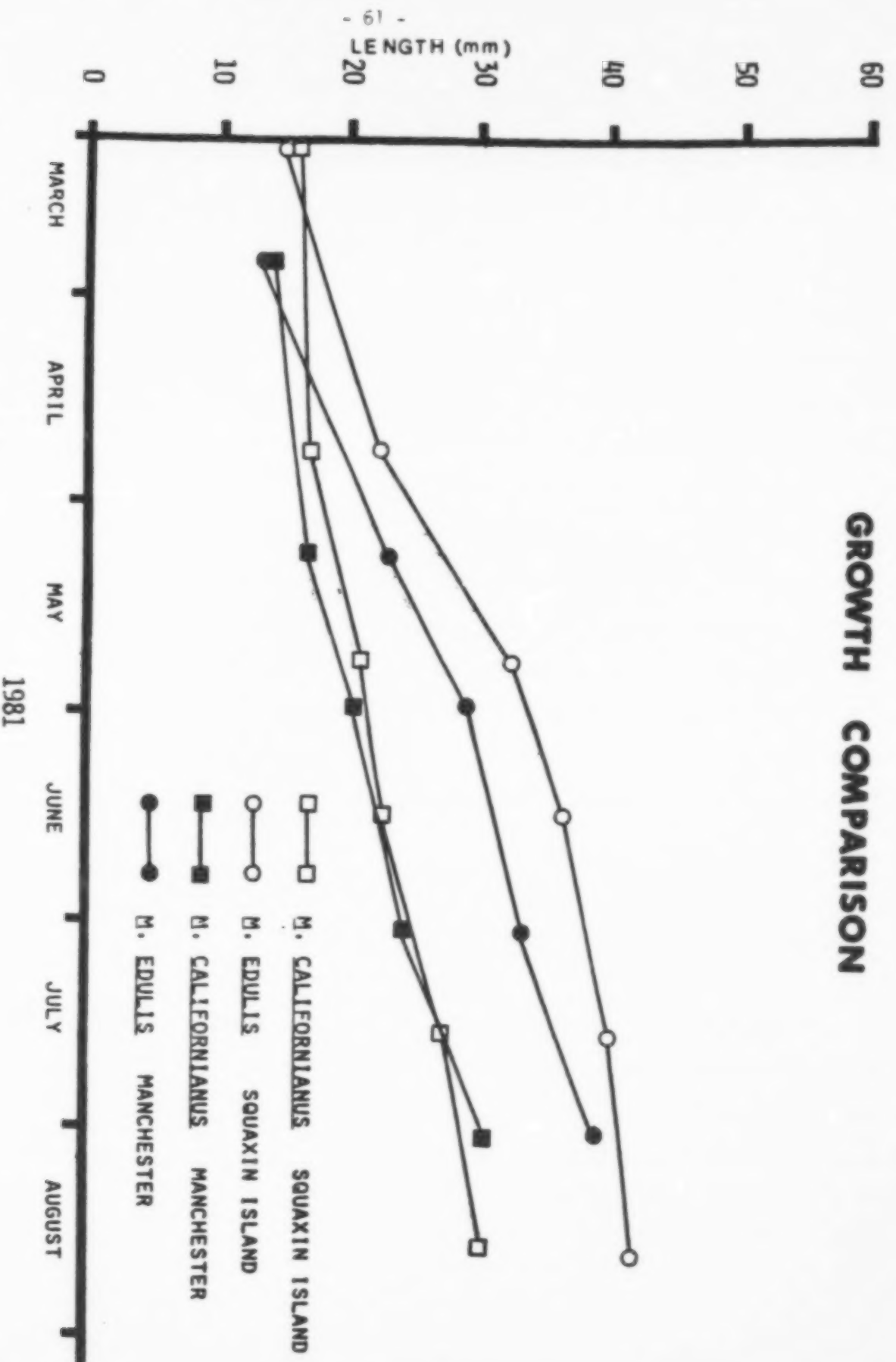


Figure 15. Survival rates of mussels by species at two locations (Kindly provided by Dr. K. Chew, University of Washington.)

Another possibility is to test the native M. edulis indigenous to Budd Inlet in the State of Washington. It is claimed by some culturists there that Budd Inlet seed will do well anywhere and is resistant to summer mortality.

The importation of exotics should be left alone.

e. Disease

Prior to the summer die-off Seakem Oceanography subjected Refuge Cove mussels to histological analysis. Whether the high incidence of ciliates found increases with the occurrence of summer die-off is not established, nor is it apparent whether a pathogen is responsible for the inflammation of hemocytes which was also observed. More recent work done by Seakem shows evidence of a blood disorder, particularly in mussels from Nanaimo. In these mussels the blood cells are in a state of rapid division and appear neoplastic (i.e., cancer-like). Dr. K. Chew (University of Washington) has observed similar conditions in Washington. It is not certain whether the condition causes mortality or if the symptom is a consequence of induced stress. A continuation of this work might shed some light on the summer die-off problem.

3. Formulation of a Grow Out Strategy for the Future

At this point we are reminded of the problems encountered by the Japanese in developing their new multimillion dollar cultured scallop industry. For years they were confronted with unacceptable seed mortalities until they learned that their indigenous scallop was highly sensitive to handling,

overcrowding and salinity changes. When they developed new handling and subsurface longline systems, their efforts were rewarded by the rapid development of a new and successful mariculture enterprise. Government, with scientist and farmer, over a considerable period of time, worked cooperatively to identify and solve their problems.

We may have a similar situation in British Columbia with our indigenous mussel. The biological, technological and economical constraints are considerable, however, there remain courses to follow before abandoning all hopes of a mussel industry in our waters. Our rope (collector-grow out) substrates represent one avenue to follow. Presently the seed on these ropes ranges between 25-35 mm, byssus attachment is numerous and strong, the density ranges between 500-1,000 individuals per meter, predation by ducks and stars is not evident and the seed is clean and unfouled. If these seed survive their second summer, then a potential grow out strategy can be commended with confidence.

4. Recommended System

In the meantime we recommend the following system. The system should be implemented on various sites and at least 300 units installed per site.

1. Suspension
 - double long line (Japanese type float)
 - space of verticals every 0.5 m
2. Cultching
 - vertical 5 m lengths of rope
 - experiment with various size diameters (13-20 mm)

- weight with rocks held in waste netlon
 - plastic rod reinforcers every 30 cm
 - units reusable for five year period
 - catch major set (site specific)
 - brush rope with hand so that seed only remains in lay of rope
 - size of seed about 5 mm
 - lower on tethers to avoid continuous setting, fouling, predation (depth culture)
 - size 15 mm average
 - saline solution dip if starfish evident in numbers
 - thin clumps which have migrated to reinforcers
 - 500-1,000 individuals/m
 - don't disturb
 - add floatation
 - periodic monitoring of growth, byssal attachment, etc.
 - when 80% of individuals over 50 mm of size
 - never harvest during summer months
 - check condition
 - market small volumes to test for mortalities and shelf life
3. Timing
4. Thinning
5. Second thinning
6. Grow out phase
7. Harvest

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